COMPARISONS OF PARTICLEBOARD PRODUCED FROM *ACACIA* HYBRID AND A UK COMMERCIAL PARTICLEBOARD FURNISH FROM RECYCLED WOOD

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SUFFIAN M, ORMONDROYD GA & HALE MD. 2010. Comparisons of particleboard produced from *Acacia* hybrid and a UK commercial particleboard furnish from recycled wood. A series of particleboards were produced from small diameter logs of *Acacia* hybrid and a UK commercial furnish (recycled wood). Physical and mechanical properties of the boards were then determined. It was hypothesised that the particleboard produced from *Acacia* hybrid would have acceptable mechanical and physical properties for the European market. Both particleboards surpassed the European standard requirements for general purpose boards (Type P1). Boards produced using *Acacia* hybrid exceeded the standard requirements for load bearing boards (Type P4). Thickness swelling and water absorption values were about half of those achieved by boards manufactured from the commercial furnish after being immersed in water for 2 and 24 hours. Similar trends could be seen when boards were immersed in water for nearly 70 hours and exposed to wet–dry cycles. The modulus of elasticity and modulus of rupture of *Acacia* hybrid were 90 and 50% greater than recycled wood respectively. The internal bond strength of the *Acacia* hybrid boards was significantly high in both dry and exposed conditions. Extreme exposure in a cyclic test (BS EN 321:1993) meant that the difference in swelling between the two furnishes became statistically insignificant.

Keywords: Urea formaldehyde, physical properties, mechanical properties

SUFFIAN M, ORMONDROYD GA & HALE MD. 2010. Perbandingan papan serpai daripada *Acacia* hibrid dengan papan serpai komersial UK yang diperbuat daripada kayu kitar semula. Satu siri papan serpai telah dihasilkan daripada batang *Acacia* hibrid berdiameter kecil dan bahan komersial UK (kayu kitar semula). Sifat fizikal dan mekanik papan kemudiannya ditentukan. Hipotesis kajian ialah papan serpai *Acacia* hibrid akan mempunyai sifat mekanik dan fizikal yang setara dengan papan serpai untuk pasaran Eropah. Kedua-dua papan serpai didapati melepasi keperluan piawai Eropah untuk papan kegunaan umum (Type P1). Papan daripada *Acacia* hibrid melebihi keperluan piawai untuk papan tahan beban (Type P4). Nilai pembengkakan ketebalan dan keserapan air adalah separuh daripada yang dihasilkan oleh bahan komersial setelah direndam dalam air selama dua jam dan juga 24 jam. Trend yang serupa diperhatikan apabila papan direndam dalam air selama hampir 70 jam dan terdedah kepada kitaran basah–kering. Modulus keanjalan dan modulus kepecahan *Acacia* hibrid adalah masing-masing 90% dan 50% lebih besar daripada kayu kitar semula. Kekuatan ikatan dalaman papan *Acacia* hibrid adalah tinggi secara signifikan dalam kedua-dua keadaan kering dan terdedah. Pendedahan terlampau dalam ujian kitaran (BS EN 321:1993) menyebabkan perbezaaan antara kedua-dua papan tidak signifikan.

INTRODUCTION

The issue of raw material for wood composites industry is important in Malaysia due to shortage of rubberwood (Yamashita *et al.* 1999, Ooi 2006). Alternative raw materials such as other plantation species, processing waste, non-wood resources and recycled wood have become priority to fulfil the needs of industry. Currently, besides rubberwood, mixed hardwood (both round wood and processing wastes) and oil palm empty fruit bunches have been used in the production of panel products (Suffian 2007, Rahim 2009).

Plantation grown timber is the major wood resource available to the particleboard industry. There are about 2 mil ha of plantations scattered throughout Malaysia and are owned by private companies, government agencies and individuals (Awang Mohdar & Ahmad Zuhaidi 2005). However, the amount of extractable timber

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remains relatively low. To ensure continuous supply of wood, a large-scale plantation programme was launched in 2007 to plant up to 25 000 ha of forest species comprising eight selected timber species (MTC 2007), *Acacia* hybrid being one of them.

Acacia hybrid is a fast-growing species originated from the hybridisation of *Acacia auriculiformis* and *Acacia mangium*, either by man-made propagation or spontaneously in nature where both parental species occur. In terms of wood utilisation, the tree has wood strength properties comparable with *A. mangium* (Mohd Shukari *et al.* 2002), which has been found to be suitable for the production of low- and medium-density particleboards (Chew *et al.* 1991, Razali & Kuo 1991). *Acacia mangium* also has comparable mechanical strength properties with particleboards from plantation species of similar wood density range, for example *Gmelina arborea* and *Araucaria hunstenii*.

Recycled wood is used throughout Europe to manufacture particleboard. Although there are issues with handling, due to preservatives, paints and other treatments, and recycled wood produces slightly inferior board compared with virgin wood of the same species, recycled wood has been adopted as the preferred furnish due primarily to economic reasons.

Nevertheless, recycled wood has been successfully used by the European particleboard industry which consumes a total of 2.6 mil tonnes of recycled wood annually (EPF 2004). All particleboard producers within the UK utilise recycled wood in their particleboard manufacture. The volume of recycled wood utilised in board manufacture is expected to increase in the foreseeable future. Recycled wood can arise from municipal solid waste, construction and demolition waste, primary timber processing and treated wood waste (Falk 1997).

It has been shown in the literature that *A. mangium* can be used to manufacture particleboard with acceptable properties. It is, therefore, hypothesised that particleboard produced from *Acacia* hybrid will have acceptable mechanical and physical properties for use in the European market (as laid out in BS EN 312:2003). This paper discusses the physical and mechanical properties of particleboard manufactured from virgin *Acacia* hybrid and European recycled wood.

MATERIALS AND METHODS

Small logs of eight-year-old *Acacia* hybrid, up to 18 cm diameter, were obtained from a plantation plot in Rantau, Negeri Sembilan, Malaysia. The logs were debarked, chipped, converted into particles using a Pallman knife-ring flaker and screened through a 0.5-mm sieve to exclude the fines. For the recycled wood particleboard, commercially produced particles were obtained from a particleboard manufacturer in the UK and screened through a 0.5-mm sieve. The composition of the furnish and the origins of the wood are variable within the recycled furnish; however the industry standard, WPIF/UKFPA/1-2000 (Wood Panel Industries Federation 2000) sets out the allowable contamination within the final board product in terms of heavy metal, creosote and pentacholorphenol concentrations and these levels are in turn based on the Euronorm Standard BS EN 71 '*Safety in Toys*' (Irle & Ormondroyd 2002). The strictness of the EN 71 (and therefore of the industry standard) preclude the use of chemically treated and the majority of painted woods in the manufacture of particleboard, with only wood that is deemed to be 'clean' entering the panel manufacturing process.

All particles were conditioned to 3% moisture content prior to board production. The particles were randomly collected and analysed with an Endecotts sieve shaker using sieves of suitable sizes (3.35, 2.80, 1.40, 1.00, 0.60, 0.25 mm). Twenty pieces of particles were randomly collected from each sieve (except 0.25-mm sieve due to small size particles) and their length, width and thickness were determined using a micrometer. The length was measured in the tangential direction. The slenderness ratio (SR) of the particles was calculated by the simple equation taken from Moslemi (1974) and shown in Equation 1:

$$\mathrm{SR} = \frac{\text{length}}{\text{thickness}} \qquad (1)$$

Ten replicates of single-layer particleboards were produced each from *Acacia* hybrid and recycled wood. A nominal thickness of 12 mm and target density of 650 kg m^{-3} were parameters for the manufacture of the boards. The particles were blended with a commercial (supplied by Dynea) urea formaldehyde resin (10% of dry wood weight) and wax (1%) in a rotary blender before being pre-pressed in a 500 × 500 mm pre-press. The mat was then pressed in a Schwabenthan press controlled with PressMan control unit. The press platens were heated to 200 °C and an initial close speed of 3 mm s^{-1} was used. The total press cycle was 3 min and this ensured full cure of the resin. All samples were cut to a set cutting pattern and then conditioned at 65% relative humidity and 20 °C until their constant weights were obtained, after which testing was undertaken.

Thickness swelling (TS) and water absorption (WA) tests were conducted on samples (50 × 50 mm) according to BS EN 317:1993 (BSI 1993a). Four replicates were taken from each of the 10 boards manufactured for each of the furnishes. The thickness and weight of boards were measured before and after soaking in water (20 ± 5 °C) for 2 and 24 hours. The differences between thickness and weights before and after immersion were expressed as percentage. The boards were immersed in water at 20 ± 5 °C for a further 24 hours followed by oven drying in a forced air oven at 103 °C. Board thickness was measured after each process. The immersion–drying cycle was repeated for a total of eight cycles.

In the water uptake test, samples were immersed in water and vacuum impregnated (using a venturi vacuum pump) at 20 °C and then left to soak for 15 hours, after which the weight increase was determined. Static bending tests were conducted on boards (270 × 50 mm) according to BS EN 310:1993 (BSI 1993b). An Instron universal testing machine (model 5500R with a 50 kN load cell), with crosshead speed 6.6 mm min^{-1}, was used to determine the modulus of rupture (MOR) and modulus of elasticity (MOE) of boards. Three replicates were taken from each of the 10 boards manufactured from each of the furnishes.

The density profile through the thickness of the boards (50 × 50 mm) was determined by means of gamma radiation transmitted using an ATR density profiler (software version 2.09) through the sample across the thickness. Eight replicates were analysed for their density profile. The boards were placed in the density profiler with their upper surface always to the top of the support rack; the rack was then lowered through a radiation source. The practice of loading samples into the equipment in the same way has led to the ability to analyse densities of the same surface on differing boards (i.e. compare lower surfaces on differing boards).

The internal bond (IB) test was carried out according to BS EN 319:1993 (BSI 1993c). The samples (50 × 50 mm) were attached to a wood block with hot-melt glue on both surfaces. The internal bond value was determined using Instron universal testing machine (model 4301, 5 kN load cell capacity) at crosshead speed of 0.8 mm min^{-1}. Four replicates were taken from each of the 10 boards manufactured from each of the furnishes.

Cyclic exposure test was carried out according to BS EN 321:1993 (BSI 1993d). Samples (50 × 50 mm) were exposed to three cycles, each comprising immersion in water at 20 °C for 72 hours, freezing at between -12 and -20 °C for 24 hours and drying at 70 °C for 72 hours. The boards were then tested for thickness swelling and internal bond strength.

All test data were analysed using a statistical computer package (SPSS version 16). Analysis was undertaken to establish means, standard deviations and the statistical significance of differences between the two sets of comparable data.

RESULTS AND DISCUSSION

Samples of particleboard were successfully produced from *Acacia* hybrid and recycled wood particles. The average core temperature development for boards manufactured from both types of furnishes are shown in Figure 1. At the end of the test, the core of *Acacia* hybrid reached a slightly higher temperature than the recycled wood even though it showed slower heat transfer. The difference was due to the materials rather than pressing system since the temperature of platens was consistent in the series of trials throughout the boards.

Particle size distributions for both woods were different due to differences in lab scale and commercial processes (Figure 2). Although the particle size distribution was different for each of the furnishes, it should be noted that the particle size distribution centred around 1.4-mm sieve mesh size with approximately 76% of the *Acacia* hybrid particles being between 0.6 and 2.8 mm in size while recycled wood had a higher volume, 83%, in same size range. The *Acacia* hybrid had considerably broader size distribution. Upon analysis of the particle dimensions it was found that particles of *Acacia* hybrid were obviously longer than that of recycled wood but at 1.4-mm sieve output and below an analysis of variance between the two sets of data showed that the difference was not statistically significant (Figure 3). Overall analysis of the chips showed that the width was not significantly different between the differing furnishes but varied as the particle size became smaller, i.e. < 1.4 mm (Figure 4). Recycled wood particles of > 2.8 mm in size were significantly thicker than *Acacia* hybrid (Figure 5). Differences in the wood type and size have been reported to give a significant effect on properties of particleboard (Maloney 1977). Miyamoto *et al.* (2002) showed that effects of small particle had a varied effect on properties of boards manufactured from Japanese cypress. Within this study particles of differing surface areas were compared and it was found that although the reduction in particle size had a positive affect on the internal bond strength and thickness swell, it did not have a significant effect on MOE and MOR.

Slenderness ratio increases with the increase of propensity of the chip to buckle. The slenderness ratio of *Acacia* hybrid was higher than recycled wood particularly on particles > 1.4 mm (Figure 6). With particles < 1.4 mm there was no significant difference between the lengths of the *Acacia* hybrid and that of recycled wood particles. Therefore, there was no significant difference between the slenderness ratios. An increase in slenderness ratio results in a stiffer and stronger board in bending but a decrease in internal bond strength (Moslemi 1974).

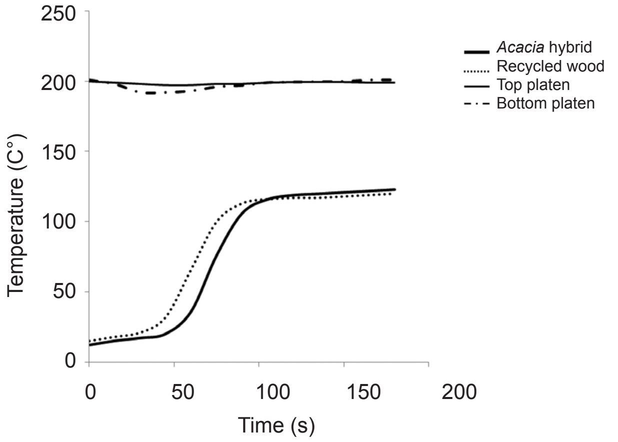

Figure 1 Temperature behaviour at the centre of *Acacia* hybrid and recycled wood mat during hot pressing

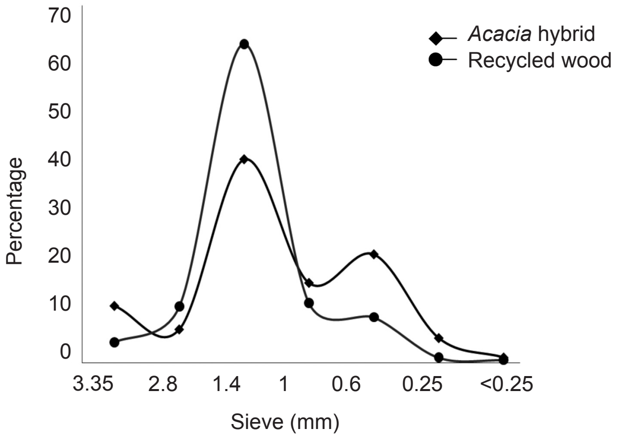

Figure 2 Distribution of *Acacia* hybrid and recycled wood particles

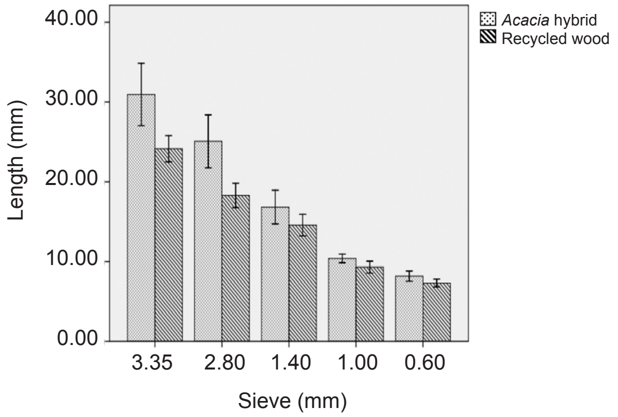

Figure 3 Length of *Acacia* hybrid and recycled wood particles

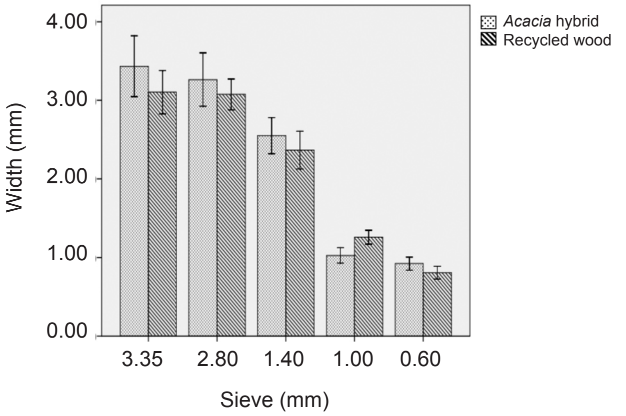

Figure 4 Width of *Acacia* hybrid and recycled wood particles

Physical properties

The density profile of a board is dependent on the particle configuration, moisture distribution in the mat, hot press temperature and rate of closing, resin reactivity and the compressive strength of the wood particles (Kelly 1977). Having compared density profiles of boards made from both recycled furnish and *Acacia* hybrid, it was observed that boards in this study had typical 'u-shape' density profiles with the peak densities near the surfaces and the lower in the core region (Figure 7). Boards from recycled wood had significantly higher density on the lower surface; however, this was not noted with the *Acacia* boards. Vertical density gradient substantially influences the properties of particleboard (Kelly 1977). Bending strength is enhanced by the presence of this gradient while tensile strength perpendicular to the panel surface and inter-laminar shear are adversely affected. The furnished mats of *Acacia* hybrid and recycled wood had similar moisture content (9.6% moisture for the recycled wood and 10.2% for the *Acacia* hybrid boards) when entering the hot press so this should not affect the profile. It is likely that the variance in peaks in the recycled wood boards is due to the pre-cure of the resinated furnish after contacting the hot press. The recycled wood had faster heat transfer that might have resulted in the pre-cure (Figure 1). Results of this study also showed that overall densities of both woods were statistically similar (Figure 8).

Boards from *Acacia* hybrid swelled to between 5 and 15% after 2 and 24 hours immersion respectively (Table 1). These values were significantly lower than recycled wood which recorded 2.0 and 2.4 times more swelling. In addition the water absorption values of the recycled wood board after 2 and 24 hour immersion were 2.4 and 2.1 times more than the *Acacia* hybrid. The thickness swelling of *Acacia*

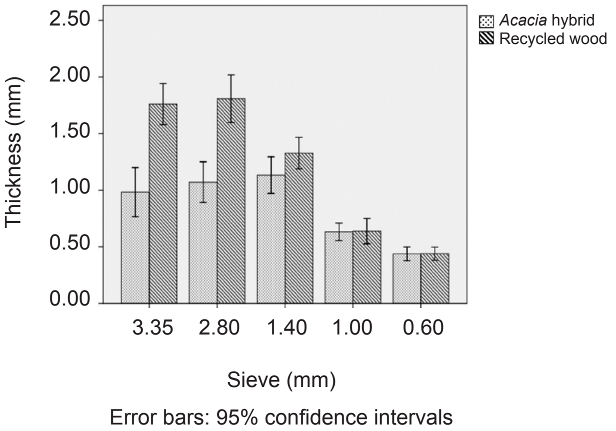

Figure 5 Thickness of *Acacia* hybrid and recycled wood particles

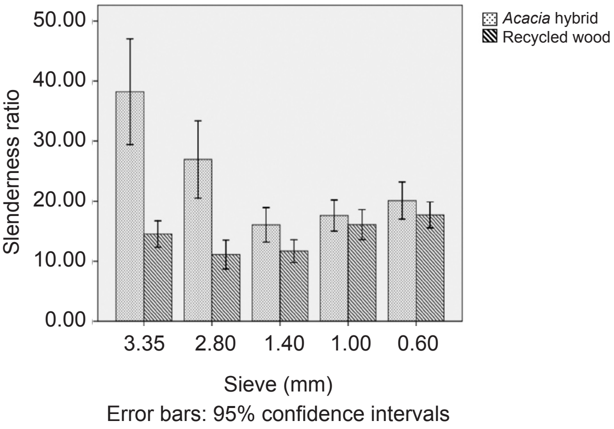

Figure 6 Slenderness ratio of *Acacia* hybrid and recycled wood particles

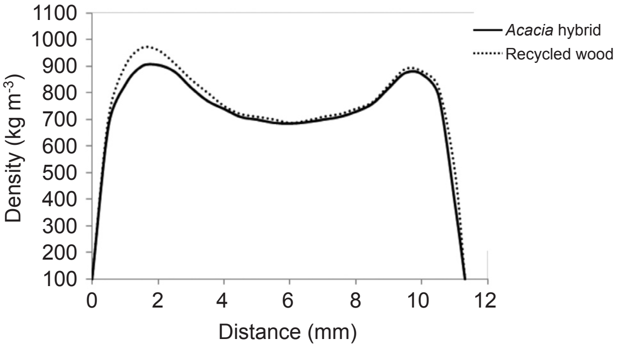

Figure 7 Density profile of particleboard from *Acacia* hybrid and recycled wood

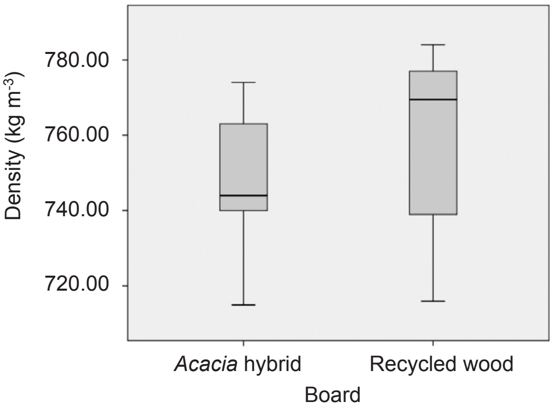

Figure 8 Density of particleboard from *Acacia* hybrid and recycled wood

hybrid was comparable with that of *A. mangium* particleboard (Razali & Kuo 1991). However, *A. mangium* particleboard produced by Chew *et al.* (1991) was five times higher.

Exposure to wet and dry cycles caused an increase in the thickness of the boards (Figure 9). Boards of *Acacia* hybrid and recycled wood had expanded up to 35 and 70% respectively by the last cycle (cycle 8). Drying of boards resulted in some recovery of thickness but not to their original thickness (about 25 and 52% respectively for *Acacia* hybrid and recycled wood). Overall, the swelling and shrinkage as well as the rates of swelling and shrinkage were smaller in *Acacia* hybrid boards.

The swelling that occurs is the sum of two components, namely, swelling by hygroscopic particles and the release of compression stresses imparted to the board during the pressing of mat in the hot press (Halligan 1970). The release of compression stresses, known as springback, is not recovered when the board is in a dry state. Even though particles of *Acacia* hybrid used to produce a board were bulkier than recycled wood, the board had less springback as shown by the recovered dimensions of dried samples. On the other hand, the recycled wood samples absorbed water more rapidly—twice the amount of water compared with *Acacia* boards. The cyclic wet–dry exposure had a considerable effect on board properties and the greatest disruption occurred by the seventh cycle. A further cycle did not significantly change the thickness swell.

The boards also had highest water absorption in the first wet exposure, i.e. before the first drying cycle (Figure 10). The water absorption values of wet exposure were inconsistent throughout the cycle. Boards of recycled wood took twice the amount of water compared with the *Acacia* hybrid. In dry condition, boards of recycled wood had lower water absorption than *Acacia* hybrid due to mass loss from the wet exposures.

The response of thickness swell and the water uptake of samples when immersed in water are shown in Figures 11 and 12. The rates of thickness swelling and water absorption values were high in the first 10 hours followed by a slower rate and after 20 hours, maximum swelling and absorption were recorded. Boards produced from recycled wood swelled nearly twice as much as the *Acacia* hybrid boards. This is in line with data shown in Table 1 and Figure 9. However, the swelling was not significantly different after 10 hours (Figure 13). The water absorption of the recycled furnish boards showed higher increment for 15 hours of exposure, then decreased and stabilised to nearly the same value as *Acacia* hybrid after 20 hours. In fact the water absorption of the two board sets was not significantly different after 1 hour of immersion (Figure 14).

The extreme exposure in the freezing cyclic test caused high thickness swell values of up to 90% (Table 2). Severe bonding loss and leaching are expected since the swelling was not significantly different between the boards.

Mechanical properties

Boards from *Acacia* hybrid had higher internal bond strength even after the wet–dry exposure and cyclic test (Tables 2 and 3). With dry boards (BS EN 319), most failure occurred at the middle whereas for exposed boards, near to the surface. The urea formaldehyde resin interacted well with

Table 1 Physical properties of particleboard from *Acacia* hybrid and recycled wood

Board	Thickness swelling (%)		Water absorption (%)	
	2 hours	24 hours	2 hours	24 hours
Acacia hybrid	5.27 b (0.43)	14.86 b (1.30)	6.11 b (0.50)	30.01 b (1.81)
Recycled wood	10.55 a (1.63)	35.70 a (3.60)	14.91 a (1.20)	63.66 a (3.51)
Type P4[1]	-	Max. 16	-	-

Values in parentheses are standard deviations (n = 8); different letter within the same row indicates significant difference at 95% confidence intervals; [1]particleboards specifications: requirements for load-bearing boards for use in dry conditions (BSI 2003).

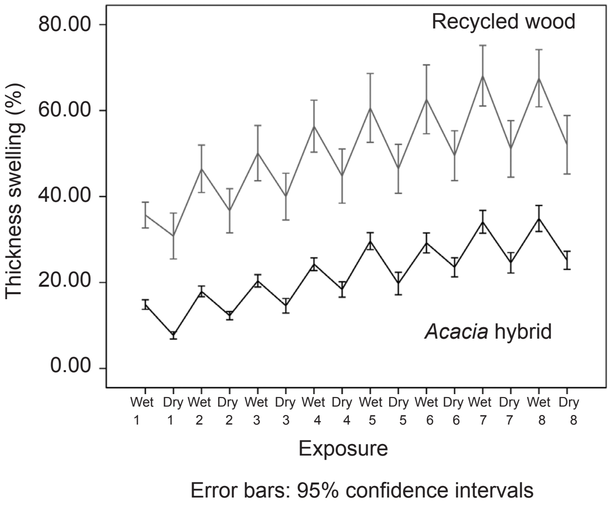

Figure 9 Thickness swelling of particleboard from *Acacia* hybrid and recycled wood after wet–dry exposure

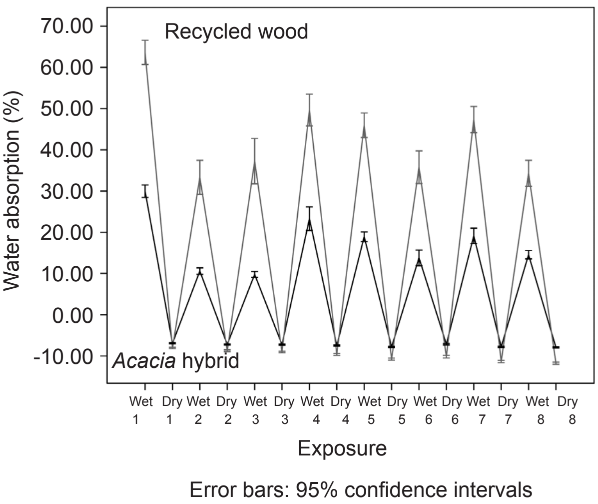

Figure 10 Water absorption of particleboard from *Acacia* hybrid and recycled wood after wet–dry exposure

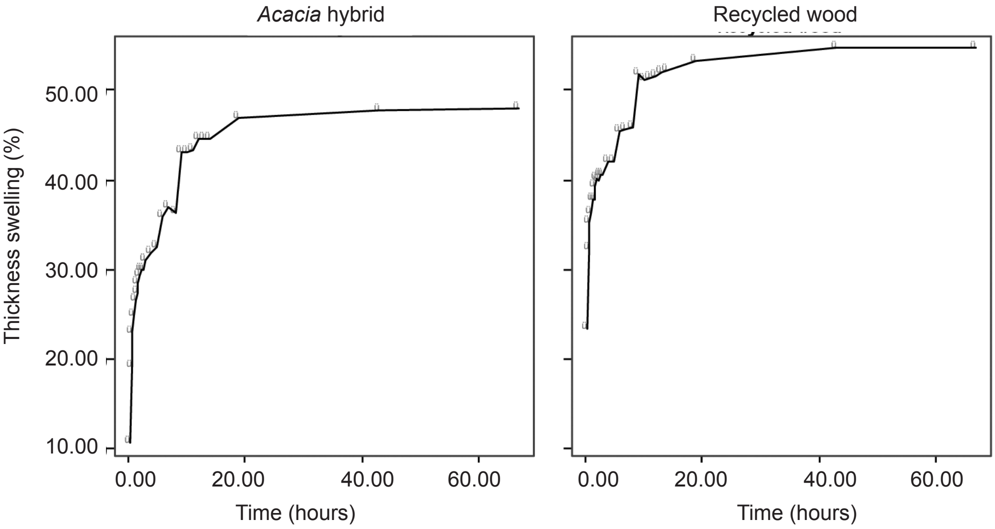

Figure 11 Thickness swelling of particleboard from *Acacia* hybrid and recycled wood from the water uptake test

Acacia hybrid to give high tensile strength. During exposures, the resin reacted with water, thus, weakening the particle bonding (as is expected with urea formaldehyde resin). Particles were being lost from boards after extreme exposures of cyclic test.

The *Acacia* hybrid board had greater MOR and MOE values (Table 3). The MOR was 90% greater (12.43 MPa) and MOE was 49% higher (1256 MPa) than recycled wood. The MOR of *Acacia* hybrid is comparable with *A. mangium* boards as reported by Razali and Kuo (1991), and slightly lower than boards produced by Chew *et al.* (1991). The internal bond strength is comparable with values reported by Razali and Kuo (1991) and Chew *et al.* (1991).

Both *Acacia* hybrid and recycled wood boards surpassed the mechanical strength requirements for general purpose applications specifed by European standard. In fact the strengths of *Acacia* hybrid boards exceeded the requirements for load-bearing board for use in dry condition (BSI 2003).

Although the particle size distributions were different within the two furnish types, both were centred on the 1.4-mm sieve size, with a large percentage of chips in the 0.6- and 2.8-mm size range. As noted earlier, Moslemi (1974) reported

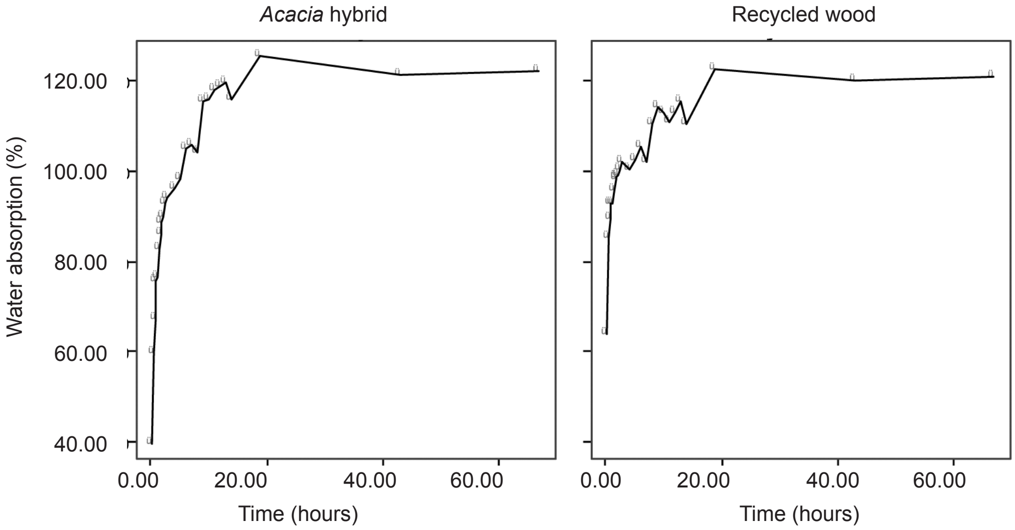

Figure 12 Water absorption of particleboard from *Acacia* hybrid and recycled wood from the water uptake test

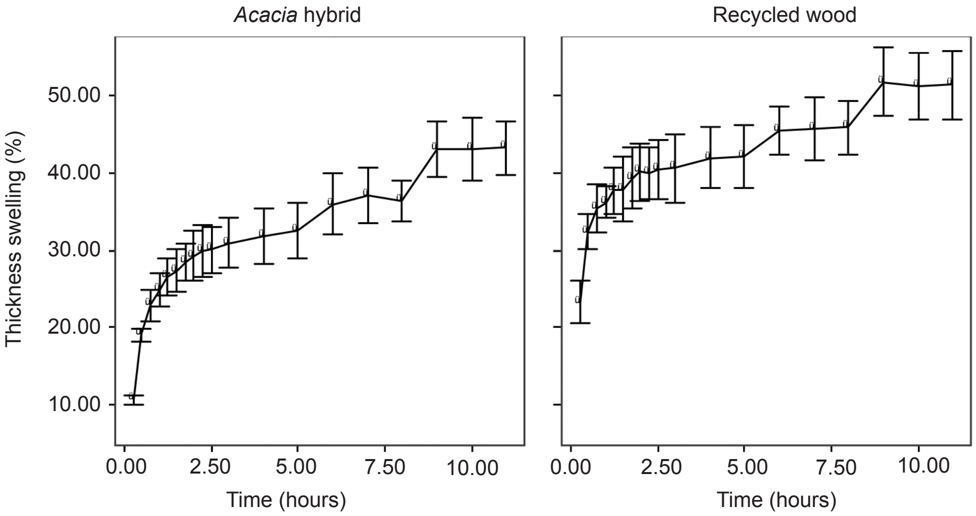

Figure 13 Statistical comparison of thickness swelling values of particleboard from *Acacia* hybrid and recycled wood from water uptake test

that an increase in slenderness ratio produces a stiffer and stronger board in bending with a decrease in the IB strength; this is in agreement with the work of Miyamoto *et al.* (2002) which states that as chips get smaller in length their internal bond strengths increase.

The slenderness ratio of *Acacia* hybrid particle was relatively higher than recycled wood. However, in this study, all properties of the *Acacia* hybrid were significantly higher than those tested for the commercial (recycled) furnish. This is contrary to what has been reported in research undertaken on effects of particle size distribution alone (Moslemi 1974, Miyamoto *et al.* 2002). It can, therefore, be inferred that the *Acacia* hybrid wood itself is having an effect on the properties of the particleboard.

CONCLUSIONS

Boards produced from *Acacia* hybrid showed better physical and mechanical properties than recycled wood. In this study, *Acacia* hybrid had consistently performed better than recycled wood. Although the increased slenderness ratio of *Acacia* hybrid particles would have had an effect on the MOE and MOR of the panels, it should be noted that the internal bond strength of the *Acacia* hybrid particleboard was higher than that of the recycled wood. This work shows

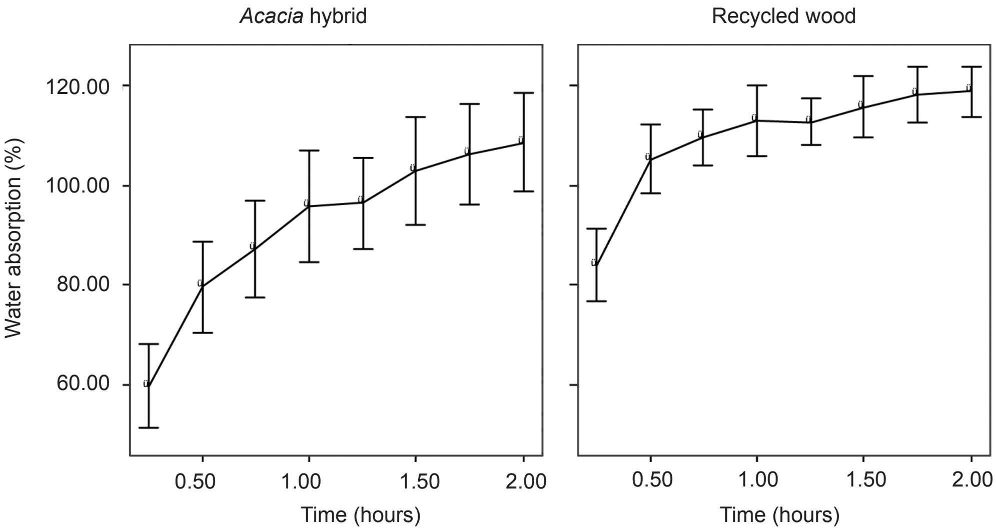

Figure 14 Statistical comparison of water absorption values of particleboard from *Acacia* hybrid and recycled wood from water uptake test

Table 2 Thickness swelling and internal bond after the freezing cyclic test of particleboard from *Acacia* hybrid and recycled wood

Board	Thickness swelling (%)	Internal bond (MPa)
Acacia hybrid	90.24a (6.59)	0.017a (0.006)
Recycled wood	83.21a (5.43)	0.011b (0.002)

Values in parentheses are standard deviations (n = 8); different letter within the same row indicates significant difference at 95% confidence intervals.

Table 3 Static bending and internal bond of particleboard from *Acacia* hybrid and recycled wood

Board	Static bending (MPa)		Internal bond (MPa)	
	Modulus of rupture	Modulus of elasticity	BS EN 319	Wet–dry exposure
Acacia hybrid	26.25a (2.29)	3811a (173)	0.95a (0.22)	0.187a (0.118)
Recycled wood	13.82b (1.98)	2555b (268)	0.61b (0.08)	0.039b (0.066)
Type P1[1]	Min. 12.5	-	Min. 0.28	-
Type P4[2]	Min. 16.0	Min. 2300	Min. 0.40	-

Values in parentheses are standard deviations (n = 8); different letter within the same row indicates significant difference at 95% confidence intervals; [1]particleboards specifications: requirements for general purpose boards for use in dry conditions (BSI 2003); [2]particleboards specifications: requirements for load-bearing boards for use in dry conditions (BSI 2003).

that the *Acacia* hybrid is a potential resource for quality particleboards.

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